The Aquatic Plant Community in Lake Hallie
Chippewa County
1991-2001
MWBC:2150200

Deborah Konkel

EXECUTIVE SUMMARY

The aquatic plant community in Lake Hallie is of average quality for Wisconsin lakes and is characterized by average diversity, abundant plant growth and a greater than average disturbance tolerance. Because of the good water clarity and shallow basin, vegetation can colonize the entire lake.

As a shallow water resource, Lake Hallie will naturally support abundant plant growth. The aquatic plants in shallow lakes provide habitat, protect the lake bottom from resuspension of sediments and compete with algae for nutrients. Without the aquatic plant community, a shallow lake can become turbid.

Lake Hallie is characterized by good water quality, fair water clarity, periodic planktonic algae blooms and abundant filamentous algae. The dense growth of aquatic vegetation is indicative of a eutrophic lake. Although the aquatic plants in Lake Hallie provides important benefits, the dense growth can hinder recreational use of the lake, consume oxygen during the winter through decomposition of the plant material and compromise the fishery by hindering the movement of predatory fish and overprotecting prey fish. Lake Hallie will likely always require management for plants, but managing with the goal of producing a community of sparse plant growth would be detrimental.

Elodea canadensis has been the dominant species within the plant community and *Potamogeton crispus* is sub-dominant during its peak growth in June. *Wolffia columbiana* became the dominant species in August 2001.

The aquatic plant community has undergone significant changes since 1991. Since a mechanical harvesting program was began in 2000, water clarity has increased, the dominance of *Potamogeton crispus* has decreased, disturbance indices have decreased, the number of species has increased and a plant species that are valuable as habitat components have increased.

Management Recommendations for Lake Hallie Lake Association
1) Preserve and expand buffer zones of native vegetation around the lake shoreline; replace mowed lawn with a buffer of natural, non-mowed vegetation at least 50 feet deep.
2) Cooperate with programs to manage run-off in the watershed.
3) Develop an aquatic plant management plan. Include mechanisms for plant modification as the plant community changes.
4) Develop a lake association budget that will provide funds for repair and maintenance of the plant harvester and pay

harvester operators.

5) Harvest during the early season to remove curly-leaf pondweed biomass from the lake before the early summer die-off and nutrient release.
6) Harvest channels in dense plant beds in mid and late summer to improve habitat and boat access and reduce amount of vegetation decomposing in the winter under the ice.

I. INTRODUCTION

Studies of the aquatic macrophytes (plants) in Lake Hallie were conducted during July 1991 and during June and August of 1998 and 2001 by Water Resources staff of the West Central Region - Department of Natural Resources (DNR). These studies were primarily conducted to determine changes in the dominance of *Potamogeton crispus* (curly-leaf pondweed) and to provide information that the Lake Hallie Lake Association could use in formulating a management plan for the curly-leaf pondweed and evaluating management success.

The study will also provide information that is important for effective management of other aspects of the lake, including fish habitat improvement, protection of sensitive wildlife areas and water resource regulations. The added data that it provides will be compared to past and future plant inventories and track changes occurring in the lake.

A study of the diversity, density, and distribution of aquatic plants is an essential component of understanding a lake due to the important ecological role of aquatic vegetation and the ability of the vegetation to characterize the water quality (Dennison et al. 1993).

Ecological Role: All other life in the lake depends on the plant life (including algae) - the beginning of the food chain. Aquatic plants provide food and shelter for fish, wildlife, and the invertebrates that in turn provide food for other organisms. Plants improve water quality, protect shorelines and lake bottoms, add to the aesthetic quality of the lake, impact recreation, and serve as indicators of water quality.

Characterize Water Quality: Aquatic plants serve as indicators of water quality because of their sensitivity to water quality parameters, such as water clarity and nutrient levels (Dennison et. al. 1993).

Background and History: Lake Hallie is a 79-acre oxbow lake near the Chippewa River in Chippewa County, Wisconsin. The maximum depth of Lake Hallie is 11 feet. Lake Hallie was once a bend in the Chippewa River that became cut-off. The northeast end of the lake has been completely cut off from the Chippewa River, but the west end of the lake still drains into the Chippewa River. Springs contribute water to the lake and the dam controls and maintains the water level.

The lake was used as a log reservoir for saw mill operations during the mid- to late-1800’s. The sawmill closed in 1890 and the lake became a recreational site. By 1990, the dam had deteriorated and needed to be repaired or removed. The dam repair at Lake Hallie was completed October 1997.

There are records of complaints pertaining to disagreeable odors from algae growth, as early as 1952. Swimmer's itch was reported in 1970. Algae/swimmer's itch treatments with copper sulfate were attempted for a few years (Table 1). Copper compounds have no long-term impact on the algae and require continuous treatments. Continual copper treatments become expensive and result in a build up of copper in the sediment. The copper contaminated sediments are toxic to some aquatic animals.

Table 1. Chemical Treatments for Algae Control.

	Copper Sulfate
1972	500
1973	250
1974	400
Totals	1150

In April 1998, a lake association was formed to address current issues and protect the lake.

In 2000, an 18-acre parcel of land was partially donated by American Materials and partially purchased by the lake association, with grants and moneys from Wisconsin DNR and Chippewa County, to protect the wetlands and springs at the northeast end of the lake.

In 2000, the lake association also received a grant to purchase a used aquatic plant harvester and started a harvesting program for curly-leaf pondweed. The main goal was to reduce the coverage and density of *Potamogeton crispus* in Lake Hallie and reduce the severity of the algae blooms that occur as the *P. crispus* decays. Other goals are:

1) Remove nutrients from the lake by harvesting plant material before the plant material dies and releases nutrients to the water.
2) Improve water quality resulting from reduced nutrient release which may eventually lead to the growth of species that are intolerant of poor clarity, creating a more diverse plant community that can support more diversity in the fish and wildlife community.
3) Immediately increase accessibility of more areas in the lake to navigation.
4) Modify the habitat by cutting openings in the dense plant beds to increase the success of predatory fish and promote a more balanced fish community.
5) Remove part of the curly-leaf pondweed from the lake and hamper its cycling of nutrients from the sediments to the water.
6) Open areas in dense beds of curly-leaf to encourage species intolerant of shading and therefore increase plant diversity.

During the winter of 2000-01, anglers reported some dead fish under the ice in Lake Hallie. Dissolved oxygen, tested in January 2001, was recorded at less than 5mg/l over most of the lake and less than 2mg/l in more than half of the lake. This is below the water quality standards for fish (5mg/l). Decay of the abundant aquatic vegetation is likely contributing to the loss of oxygen in the winter. Aeration has been used to correct the situation; removal of flashboards to pull water with low dissolved oxygen off of the bottom of the lake also appeared to keep oxygen levels higher.

II.METHODS

Field Methods

The same methods and sampling sites were used for the 1991, 1998 and 2001 aquatic plant studies, based primarily on the rake-sampling method developed by Jessen and Lound (1962). Transects (16) were place equidistant along the shoreline, perpendicular to the shoreline and mapped.

One sampling site was randomly located in each depth zone (0-1.5ft, 1.5-5ft, 5-10ft, and 10-20ft) along each transect. Using a long-handled, steel, thatching rake, four rake samples were taken at each sampling site. The four samples were taken from each quarter of a 6-foot diameter quadrat. The aquatic plant species that were present on each rake sample were recorded and each species was given a density rating (0-5) based on the number of rake samples on which it was present at each sampling site.
A rating of 1 for each species present on one rake sample;
A rating of 2 for each species present on two rake samples;
A rating of 3 for each species present on three rake samples;
A rating of 4 for each species present on four rake samples;
A rating of 5 indicates that a species was abundant on all rake samples at that sampling site.

The sediment type at each sampling site was recorded. The type of shoreline cover was recorded at each transect. A section of shoreline, 50 feet on either side of the transect intercept with the shore and 30 feet back from the shore, was evaluated. The percentage of each cover type within this 100' x 30' rectangle was recorded.

Visual inspection and periodic samples were taken between transect lines in order to record the presence of any species that did not occur at the sampling sites. Specimens of all plant species present were collected and saved in a cooler for later preparation of voucher specimens. Nomenclature was according to Gleason and Cronquist (1991).

Data Analysis

Data from each survey was analyzed separately and compared. The percent frequency of each species was calculated (number of sampling sites at which it occurred / total number of sampling sites) and relative frequency was calculated based on the number of occurrences of a species relative to total occurrence of all species (Appendix I-V). The mean density was calculated for each species (sum of a species' density ratings / number of sampling sites); relative density was calculated based on a species density relative to total plant densities; a "mean density where present" was calculated for each species (sum of a species' density ratings / number of sampling sites at which the species occurred) (Appendix VI-X). The relative frequency and relative density was summed to obtain a Dominance Value (Appendix XI-XV).

Simpson's Diversity Index was calculated (Appendix I-V) to measure species diversity and Coefficients of Community Similarity were calculated.

The Aquatic Macrophyte Community Index (AMCI) developed by Weber et. al. (1995) was applied to Lake Hallie. Values between 0 and 10 are given for each of six categories that characterize the quality of the aquatic macrophyte community.

Floristic Quality Index evaluates the closeness of an aquatic plant community to an undisturbed condition (Nichols 1998). A Coefficient of Conservatism (C) is an assigned value, 0-10, based on the probability that a species will occur in a relatively undisturbed habitat. The Average Coefficient of Conservatism ($\hat{c}$) is the mean of the coefficients of conservatism for all species found in a lake. Floristic quality (I), calculated from the coefficients, is a measure of plant community's closeness to an undisturbed condition.

II. RESULTS

PHYSICAL DATA

Many physical parameters are important determinants of the type of macrophyte community that will ultimately inhabit a lake. Water quality (nutrient concentrations, algae growth, clarity, pH) impact the macrophyte community as the macrophyte community can in turn modify these parameters. Lake Morphology, sediment composition and shoreline land use also impact the macrophyte community.

WATER QUALITY - The trophic state of a lake is an indication of its water quality. Phosphorus concentration, chlorophyll concentration, and water clarity data are collected and combined to determine the trophic state.

Eutrophic lakes are high in nutrients and support a large biomass.

Oligotrophic lakes are low in nutrients and support limited plant growth and smaller fish populations.

Mesotrophic lakes have intermediate levels of nutrients and biomass.

Nutrients

Phosphorus is a limiting nutrient in many Wisconsin lakes. So, increases in phosphorus in a lake can feed algae blooms and excess plant growth.

2001 mean summer phosphorus in Lake Hallie was 23 ug/l.

The summer phosphorus ranged from 22 ug/l-25ug/l (Appendix XII). This concentration of phosphorus in Lake Hallie was indicative of a mesotrophic lake (Table 2). Phosphorus has decreased since 1991.

Table 2. Trophic Status

	Quality Index	Phosphorus ug/l	Chlorophyll ug/l	Secchi Disc ft.
Oligotrophic	Excellent	<1	<1	> 19
	Very Good	1-10	1-5	8-19
Mesotrophic	Good	10-30	5-10	6-8
Eutrophic	Fair	30-50	10-15	5-6
	Poor	50-150	15-30	3-4
Hypereutrophic	Very Poor	>150	>30	>3
Lake Hallie 1991	Good	30	8.67	8.4
Lake Hallie 2001	Good	23	5.67	6.8

After Lillie & Mason (1983)
Shaw et. al. (1993)

Algae

Measuring the concentration of chlorophyll in the water gives an indication of algae levels. Algae is natural and essential in lakes, but high algae levels can increase turbidity and reduce the light available for plant growth.
2001 mean summer chlorophyll in Lake Hallie was 5.67 ug/l.
Chlorophyll concentrations also indicate that Lake Hallie was a mesotrophic lake (Table 2). The chlorophyll (algae) concentration in Lake Hallie has decreased since 1991.

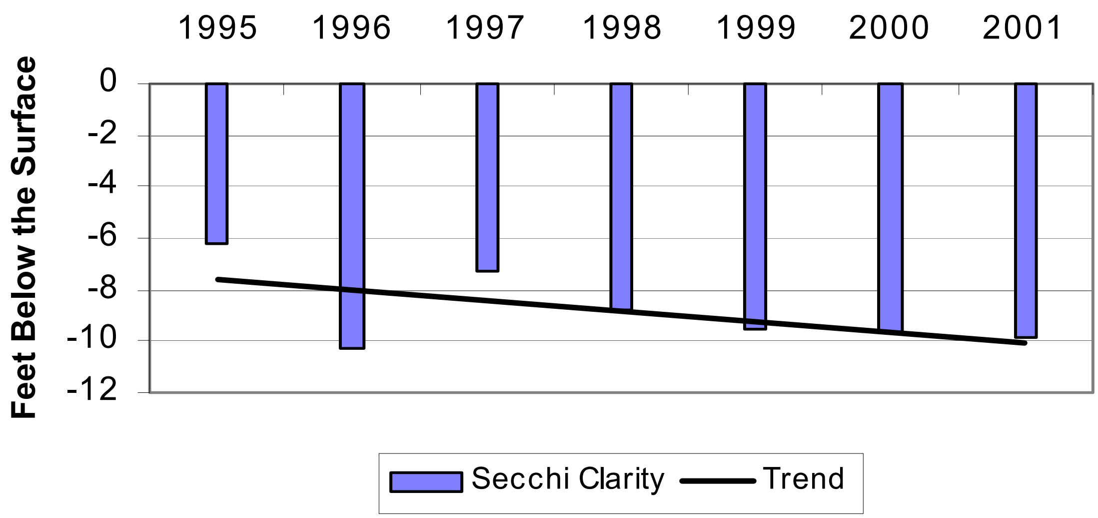
Water Clarity

Water clarity is a critical factor for plants. When plants receive less than 1 - 2% of the surface illumination, they can not survive. Water clarity is reduced by turbidity (suspended materials such as algae and silt) and dissolved organic chemicals that color the water. Water clarity can be measured with a Secchi disc that shows the combined impact of turbidity and color.
2001 Mean summer Secchi Disc Clarity was 6.8 ft.
The water clarity indicates that Lake Hallie was a mesotrophic lake that had fair water clarity in 2001 (Table 2).
Water clarity has decreased since 1991 (Table 2). Water clarity data can be used to calculate a predicted maximum rooting depth for plants in the lake (Dunst 1982).
Based on the clarity, the predicted maximum rooting depth was 11 ft. in the Lake Hallie.

George Wanserski has been monitoring the water clarity in Lake Hallie since 1995 as a volunteer lake monitor in the Self-Help

Lake Monitoring Program. The Self-Help Volunteer Monitoring data is valuable because the volunteer collects data more frequently throughout the season and for more consecutive years than Department of Natural Resource monitoring.

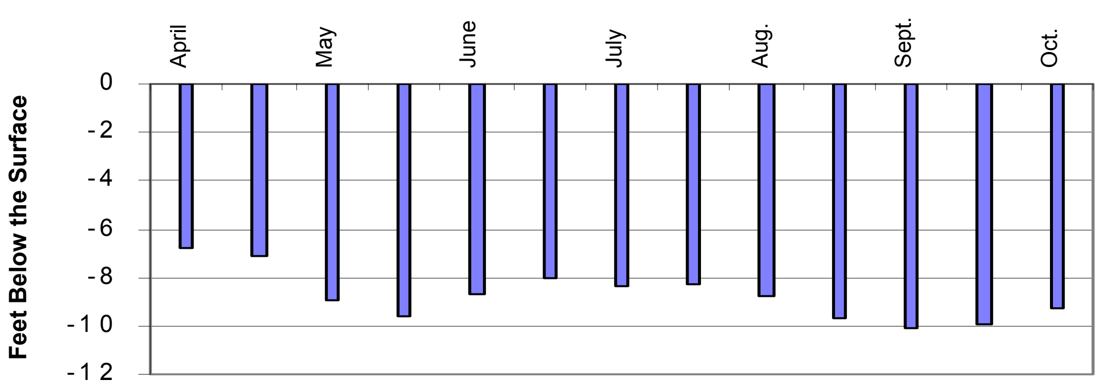
George Wanserski's data showed that the mean water clarity was greatest in 1996 (10.5 feet). The 1997 mean clarity decreased to 7.3 feet (Figure 1). Water clarity has been increasing since



1997.

Figure 1. Mean water clarity in Lake Hallie, 1995-2001.

The data collected by George Wanserski also shows that the clarity changes during the season. The 1995-2001 mean clarity for each week increases early to the greatest clarity in Late-May. The clarity decreases to its lowest clarity in Late-July. The clarity increases again to a second maximum in Late-September



and remains fairly constant during the autumn (Figure 2).
Figure 2. Changes in mean clarity during the season, 1995-2001.

The relationship between phosphorus concentration, chlorophyll concentration, and water clarity indicates the trophic status of a lake. These values for Lake Hallie would indicate that it is a mesotrophic lake with good water quality. This trophic state favors moderate levels of plant or algae growth.

Although the trophic state parameters indicate that Lake Hallie would be considered a mesotrophic lake, the dense growth of aquatic plants suggests a eutrophic shallow lake currently in the aquatic plant dominated phase.

pH

The pH of a lake indicates the acidity or alkalinity of the water.
The 2001 mean summer pH of the surface water in Lake Hallie was 8.4.
This favors plant species adapted to alkaline/neutral conditions.

LAKE MORPHOMETRY - The morphometry of a lake is an important factor in determining the distribution of aquatic plants. Duarte and Kalff (1986) found that the slope of the littoral zone could explain 72% of the observed variability in the growth of submerged plants. Gentle slopes support more plant growth than steep slopes (Engel 1985). Lake Hallie has a narrow, V-shape basin, and a mean depth of 6 feet. Most of the basin has a gradually sloped littoral zone. The gradual slope and shallow depths of Lake Hallie favor abundant plant growth.

SEDIMENT COMPOSITION - Many plants depend on the sediment in which they are rooted for their nutrients. The richness or sterility of the sediment will determine the type and abundance of macrophyte species that can survive in a location.

Silt sediment was the predominant sediment in Lake Hallie, especially in the deeper depth zones (Table 3). Silt occurred at slightly more than half of the sample sites (Table 3). The availability of mineral nutrients for growth is highest in sediments of intermediate density, such as silt (Barko and Smart 1986).

Sand, gravel and rock are high density sediments. Sand, rock and mixtures of the two were predominant in the shallow zone. All sediment types supported vegetation at high frequencies in Lake Hallie.

Table 3. Sediment Composition

		0-1.5 ft	1.5-5 ft	5-9 ft	9-10.5 ft	Overall
Soft Sediments	Silt	12%	38%	100%	100%	49%
	Peat	6%				2%
Mixed Sediments	Sand/Silt	6%	44%			17%
Hard Sediments	Sand	44%	12%			19%
	Sand/Gravel	19%	6%			8%
	Rock	12%				4%

SHORELINE LAND USE - Land use practices strongly impact the aquatic plant community and, therefore, the entire aquatic community. Practices on shore can directly impact the plant community through increased sedimentation from erosion, increased nutrients from fertilizer run-off and soil erosion and increased toxics from farmland and urban run-off.

Native herbaceous cover was the most frequently encountered shoreline cover at the transects. Shrub, wooded and cultivated lawn were also commonly encountered (Table 4). Cultivated lawn had the highest mean coverage, it covered more than one-third of the shoreline (Table 4).

Table 4. Shoreline Land Use

	Cover Type	**Frequency of Occurrences at Transects**	**Mean % Coverage**
Natural Shoreline	Native Herbaceous	75%	15%
	Shrub	50%	15%
	Wooded	44%	32%
Disturbed Shoreline	Cultivated Lawn	56%	38%
	Eroded Soil	6%	0.3%
	Hard Structures	6%	1%

Some type of natural shoreline (wooded, shrub, native herbaceous) was found at all of the sites and covered of 62% of the shoreline. Some type of disturbed shoreline (cultivated lawn, eroded and hard structures) was found at 62% of the sites and covered 39% of the shoreline.

MACROPHYTE DATA

SPECIES PRESENT

A total of 32 species was found in Lake Hallie. Of the 32 species, 14 were emergent species, 4 were a floating-leaf species, and 14 were submergent species (Table 5).

No endangered or threatened species were found.
One species of special concern was found in 1991: *Eleocharis robbinsii.*
One non-native species was found: *Potamogeton crispus*

Table 5. Lake Hallie Aquatic Plant Species

Scientific Name	Common Name	I. D. Code
Emergent Species		
1) *Calla palustris* L.	water arum	calpa
2) *Carex comosa* F. Boot.	bristly sedge	carco
3) *Eleocharis robbinsii* Oakes.	Robbin's spikerush	elero
4) *Impatiens biflora* .	pale jewelweed	impbi
5) *Iris versicolor* L.	blue flag iris	irive
6) *Juncus effusus* L.	soft rush	junef
7) *Leersia oryzoides* (L.) Swartz.	rice cut-grass	leeor
8) *Myosotis laxa* Lehm.	smaller forget-me-not	myola
9) *Phalaris arundinacea* L.	reed canary grass	phaar
10) *Rorippa nasturtium-aquatica* (L.) Hay.	water-cress	rorna
11) *Sagittaria rigida* Pursh.	stiff arrowhead	sagri
12) *Scirpus validus* Vahl.	softstem bulrush	sciva
13) *Typha angustifolia* L.	narrow-leaf cattail	typan
14) *Typha latifolia* L.	common cattail	typla
Floating Species		
15) *Lemna minor* L.	small duckweed	lemmi
16) *Lemna trisulca* L.	forked duckweed	lemtr
17) *Spirodela polyrhiza* (L.) Schleiden.	greater duckweed	spipo
18) *Wolffia columbiana* Karsten.	common watermeal	wolco
Submergent Species		
19) *Ceratophyllum demersum* L.	coontail	cerde
20) *Chara* sp.	muskgrass	chasp
21) *Elatine minima* (Nutt.) Fisch. & Meyer	waterwort	elami
22) *Eleocharis acicularis* (L.) Roemer & Schultes.	needle spikerush	eleac
23) *Elodea canadensis* Michx.	common water-weed	eloca
24) *Najas flexilis* (Willd.) R. & S.	northern water-nymph	najfl
25) *Nitella* sp.	nitella	nitsp
26) *Potamogeton amplifolius* Tuckerman.	large-leaf pondweed	potam
27) *Potamogeton crispus* L.	curly-leaf pondweed	potcr
28) *Potamogeton foliosus* Raf.	leafy pondweed	potfo
29) *Potamogeton pusillus* L.	slender pondweed	potpu
30) *Potamogeton robbinsii* Oakes.	fern-leaf pondweed	potro
31) *Potamogeton zosteriformis* Fern.	flatstem pondweed	potzo
32) *Ranunculus longirostris* Godron.	white watercrowfoot	ranlo

FREQUENCY OF OCCURRENCE

Of the 32 species found in Lake Hallie, 19 occurred at sampling sites in 1991; 14-18 species occurred at the sampling sites in 1998; 20-21 occurred at the sampling sites in 2001.

The species with the highest frequency of occurrence in all surveys was *Elodea canadensis* (Table 6). *Potamogeton robbinsii* has increased since 1991; *Chara* and *Spriodela polyrhiza* have decreased since 1991.

The frequency of *Potamogeton crispus* has been higher during June surveys: *P. crispus* increased in 1998, but declined substantially in 2001 (Table 6).

Table 6. Most frequently occurring species

	Jul'91	Jun'98	Jun'01	Aug'98	Aug'01
Elodea canadensis	**94%**	**88%**	**94%**	**86%**	**88%**
Ceratophyllum demersum	29%	4%	51%	14%	59%
Chara sp.	73%	8%	4%	30%	
Potamogeton crispus	14%	73%	40%	24%	4%
Lemna minor	65%	25%	34%	26%	49%
Wolffia columbiana	63%	25%	49%	36%	86%
Spirodela polyrhiza	55%	6%		6%	4%
Potamogeton robbinsii		12%	66%	46%	78%

Filamentous algae occurred at 100% of the sample sites in 1991.
67% of the sites in June 1998.
69% of the sites in August 1998.
96% of the sites in June and August 2001

DENSITY

Elodea canadensis had the highest mean density (2.44-3.33 on a density scale of 1-4) of any species in Lake Hallie (Table 7), except in August 2001; *Wolffia columbiana* had the highest mean density (2.69) in August 2001.

The density of *Potamogeton crispus* decreases from June to August. *P. crispus* density has decreased substantially since 1998 (Table 7). Since 1991, the density of *Potamogeton robbinsii* has increased substantially and *Chara* has decreased substantially (Table 7).

Table 7. Species with the highest mean density.

	Jul'91	Jun'98	Jun'01	Aug'98	Aug'01
Elodea canadensis	**3.33**	**2.44**	**3.06**	**3.20**	2.69
Ceratophyllum demsersum	0.45	0.06	1.17	0.20	1.24
Chara sp.	2.47	0.13	0.04	0.56	
Potamogeton crispus	0.27	2.21	0.72	0.40	0.04
Wolffia columbiana	1.63	0.73	1.74	1.08	**2.96**
Lemna minor	1.12	0.75	0.85	0.56	0.86
Potamogeton robbinsii	0	0.25	1.70	1.00	2.35

DOMINANCE

Combining relative frequency and relative density into an dominance value indicates the dominance of species within the macrophyte community (Appendix X-XV). Based on the dominance value, *Elodea canadensis* was the dominant species within the macrophyte community in 1991 and through the early summer of 2001 (Figure 3). *Wolffia columbiana* became the dominant species in August 2001.

Potamogeton crispus was sub-dominant during June 1998 (Figure 3). The dominance of *P. crispus* decreased in August surveys due to its early season life cycle. Its dominance also decreased in 2001.

Chara sp., which has declined in dominance, requires good water clarity. *Potamogeton robbinsii* has increased in dominance, becoming sub-dominant since late summer of 1998 (Figure 3). The sum of the other species' dominance has decreased, suggesting lowered diversity.

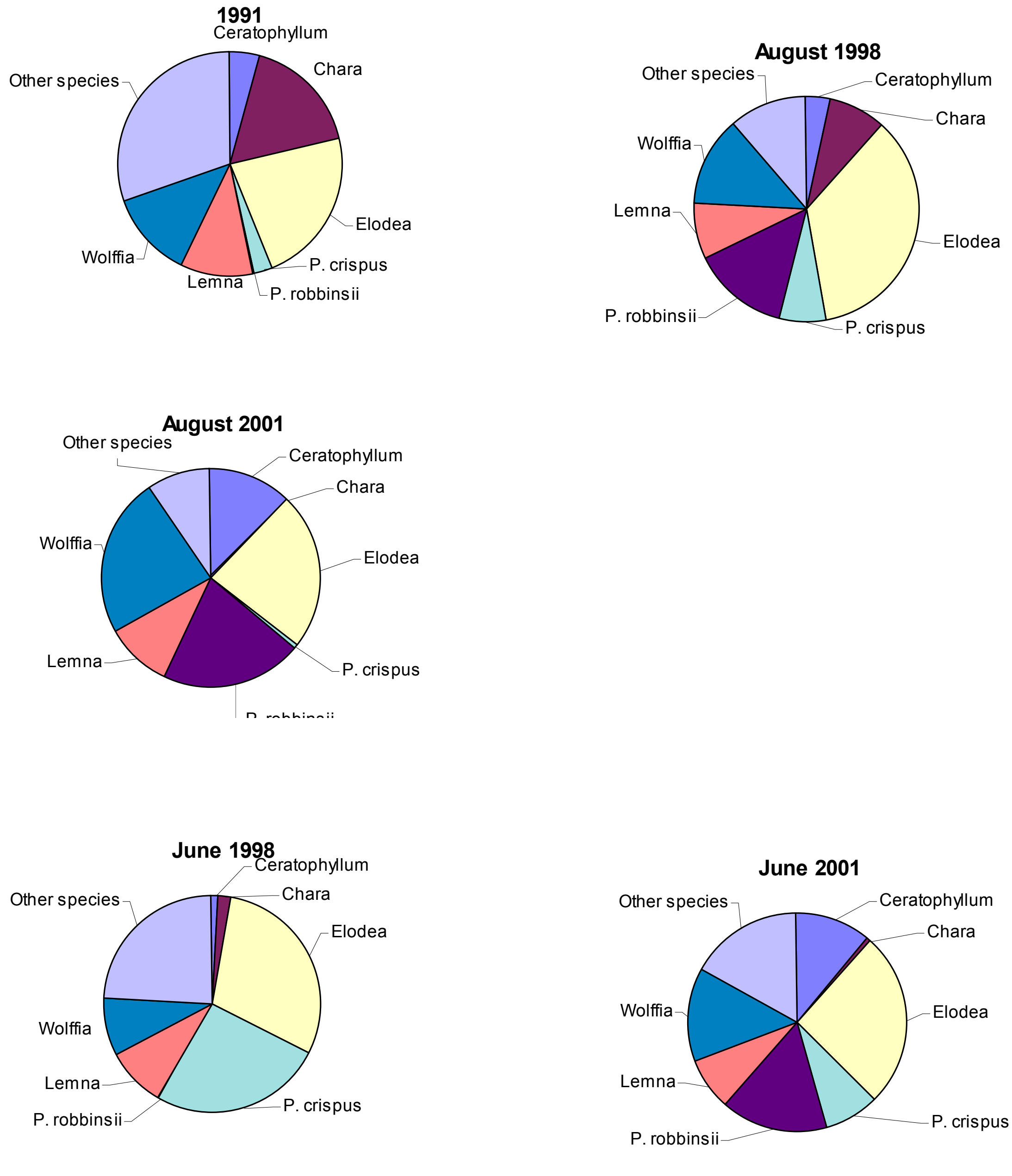
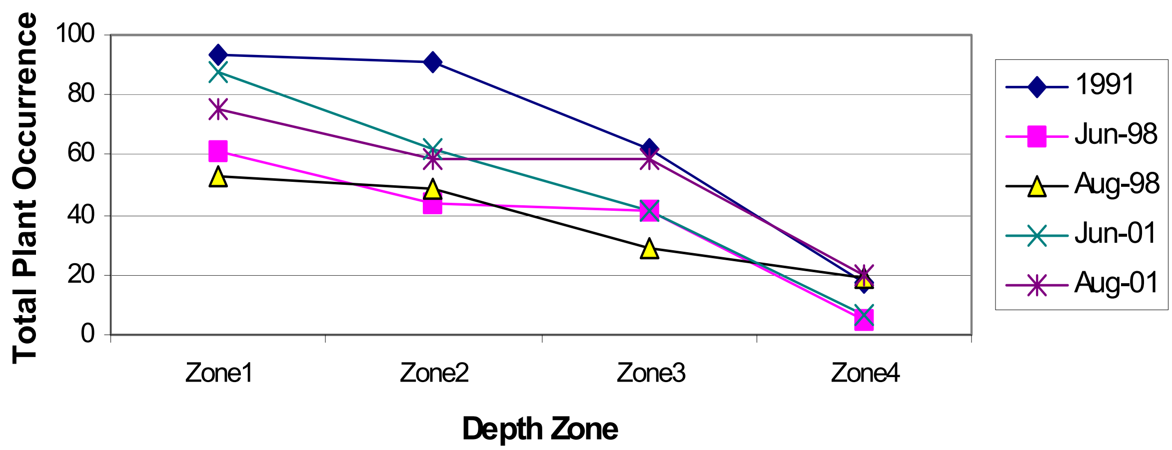


Figure 3. Dominance within the macrophyte community, of prevalent aquatic plants.

DISTRIBUTION

Aquatic plants were found growing at 94 - 100% of the sampling sites in Lake Hallie. The prevalent species were found throughout the Lake Hallie and all depth zones have had a high percentage of vegetated sites (90% or more) in all studies *Ceratophyllum demersum, Chara, Elodea canadensis* and *Potamogeton crispus, P. robbinsii* were found at the maximum rooting depth of 11.5 ft.

The 0-1.5 ft. depth zone had the highest total occurrence and total density of plants, in all studies (Figure 4, 5). The occurrence and density of macrophyte growth decreased with increasing depth. The highest total occurrence and density of



plant growth in all depth zones occurred in July 1991.

Figure 4. Total occurrence of plants by depth zone

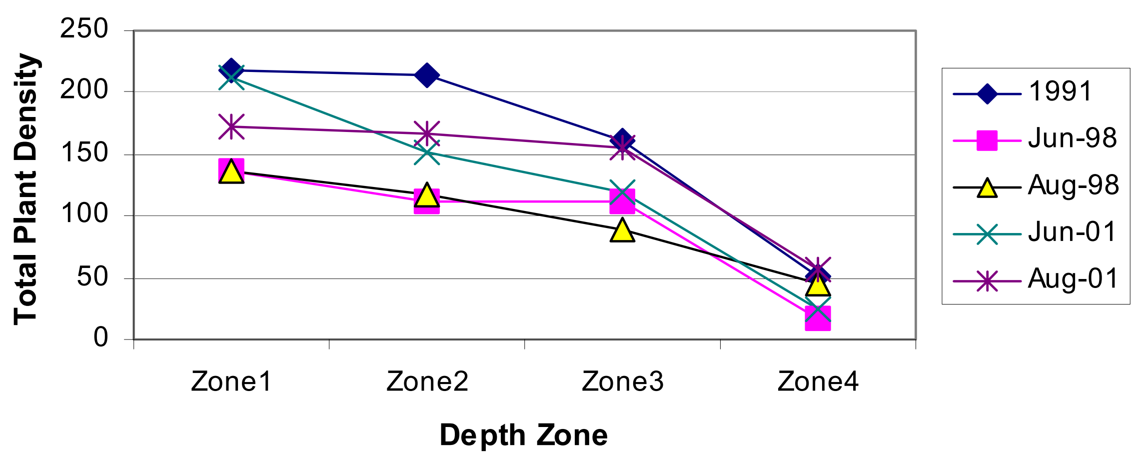
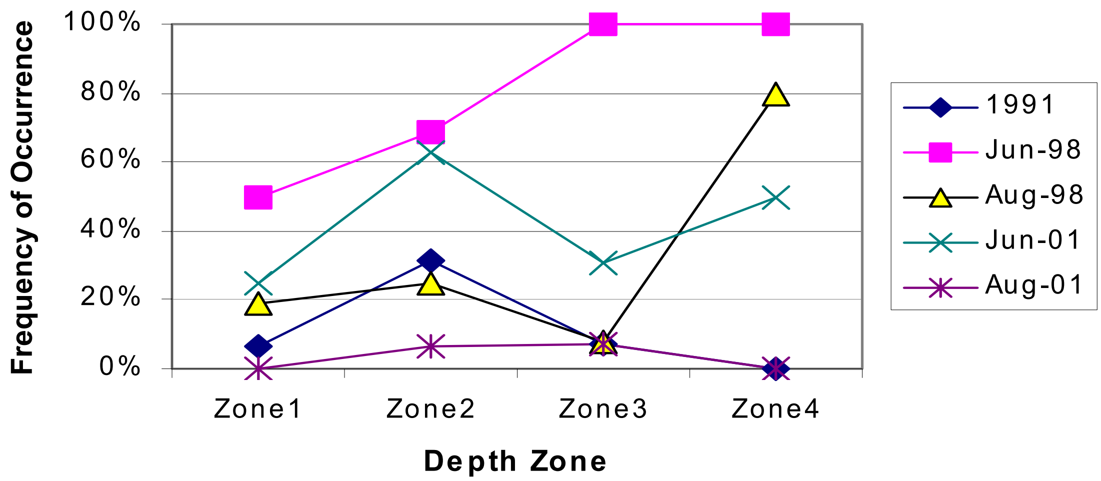


Figure 5. Total density of plants by depth zone.

The frequencies and densities of individual species varied in different years and with depth zone. *Potamogeton crispus* occurred at its highest frequency and density in June 1998 (Figure 6, 7) when it was the dominant species at depths greater than 5ft. Because of its life cycle, *P. crispus* has been more frequent and dense in June than in August in both 1998 and 2001. The frequency and density of *P. crispus* was lowest in 2001, especially in August. The late summer decrease in frequency and density of *P. crispus* followed a different pattern in 1998 and 2001. The greatest decrease of *P. crispus* was in the shallower depth zone in 1998 (likely due to the colder water in the deeper zones). The greatest was in the deeper depth zones in 2001



(likely due to the harvesting).

Figure 6. Frequency of *Potamogeton crispus* by depth zone.

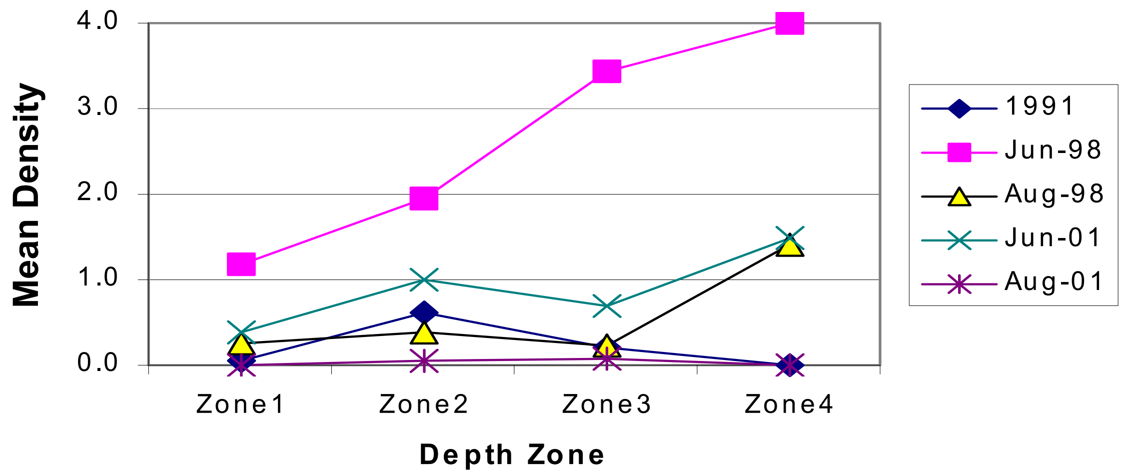
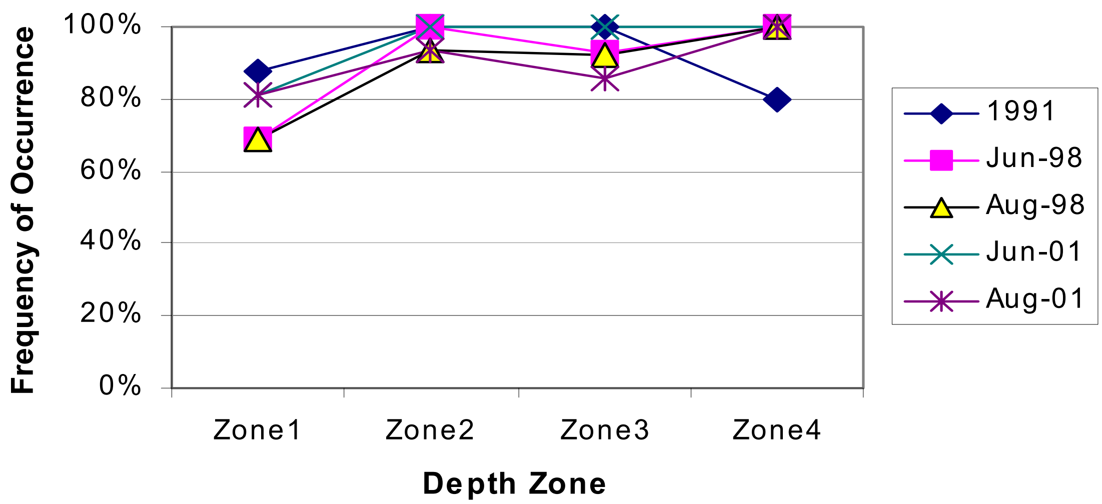


Figure 7. Density of *Potamogeton crispus* by depth zone.

Elodea canadensis was the dominant species overall in each study



(Figure 8, 9) and the dominant species in the 1.5-5ft depth zone.

Figure 8. Frequency of *Elodea canadensis* by depth, 1991-2001.

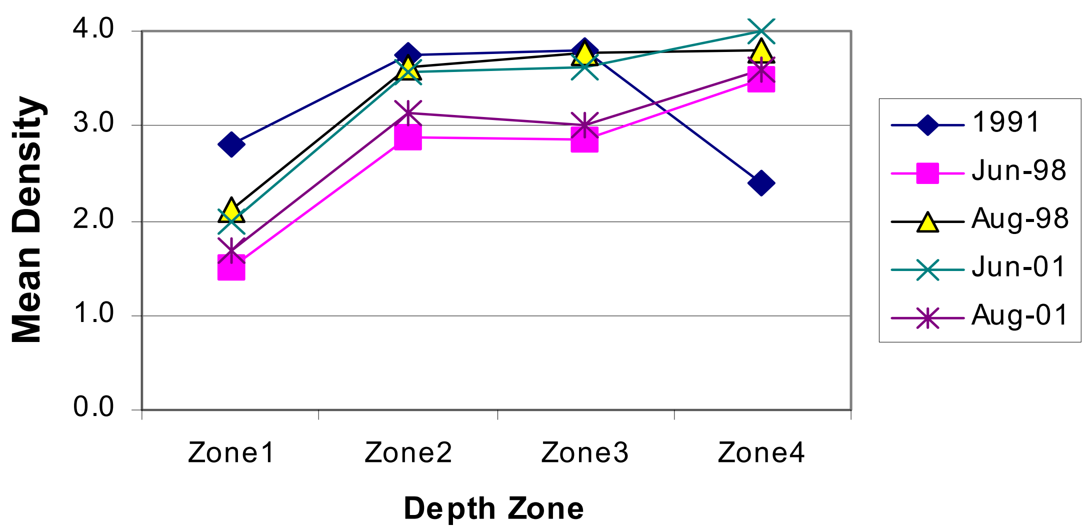


Figure 9. Density of *Elodea canadensis* by depth, 1991-2001.

Chara sp. has steadily declined in Lake Hallie, first in the shallower depth zones (Figure 10, 11). It was not found in August 2001.

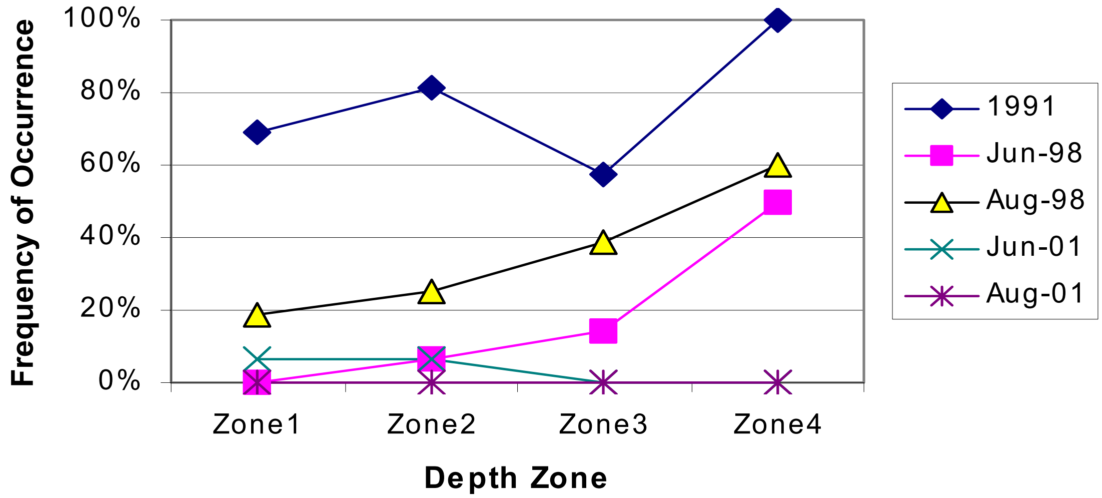
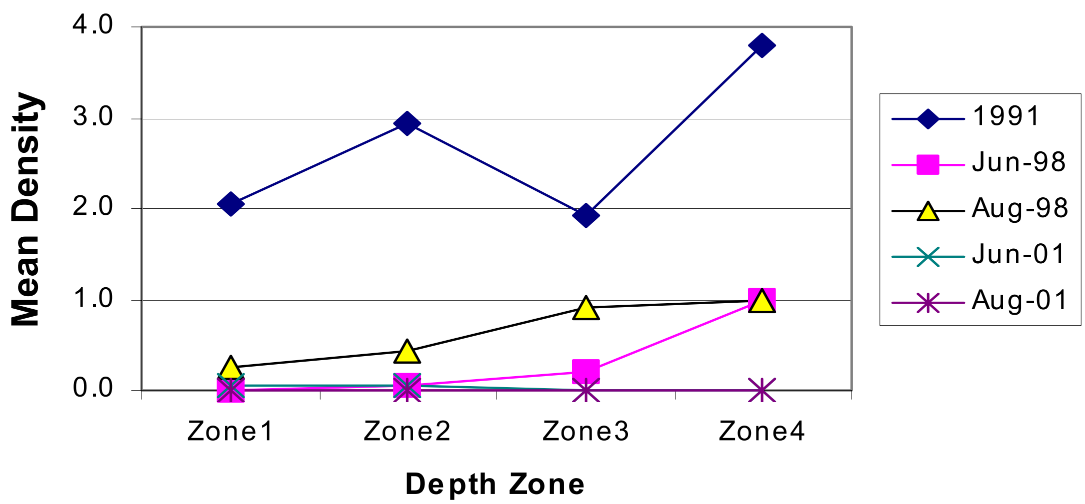


Figure 10. Frequency of *Chara* sp. by depth zone, 1991-2001.

Figure 11. Density of *Chara* sp. by depth zone, 1991-2001.

The combined densities of all the duckweed species (*Lemna minor, Spirodela polyrhiza, Wolffia columbiana*) decreased from 1991-1998 (Figure 12). From 1998-2001, the density of the duckweed species have increased. The frequency and density of duckweeds have been greatest in the 0-1.5 ft. depth zone. *W. columbiana* became the dominant species in the shallow zone in 2001.



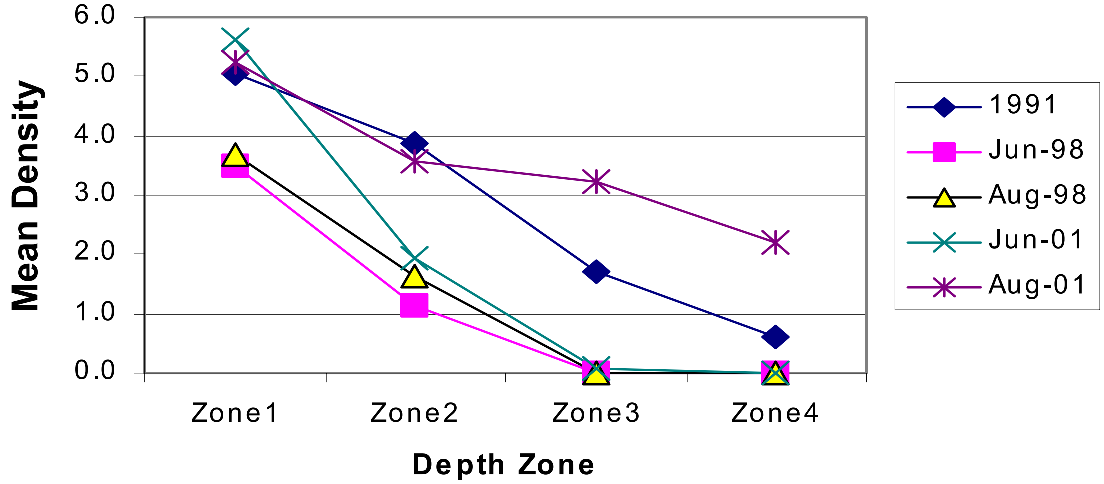
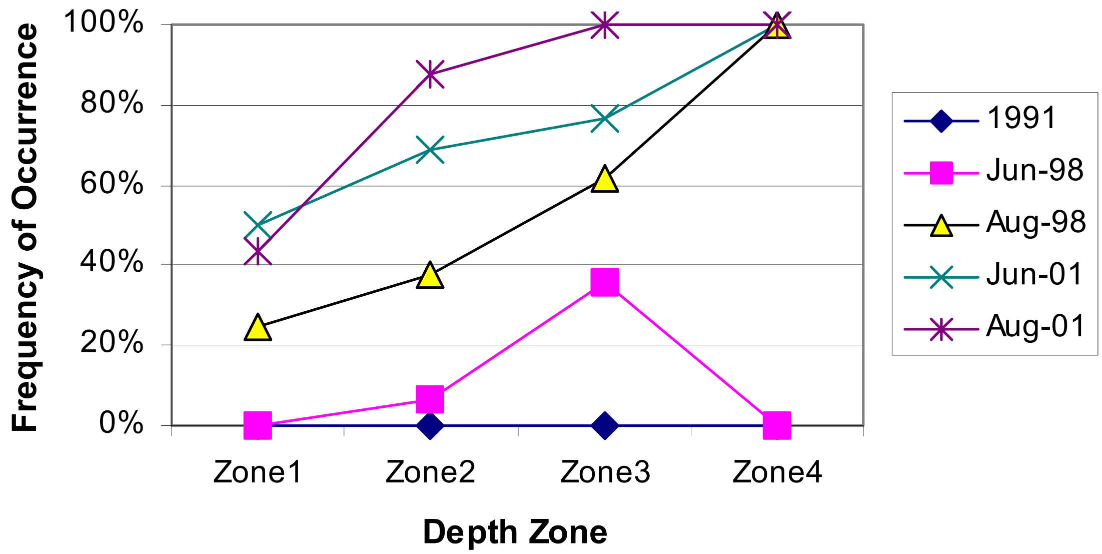


Figure 12. Density of duckweed species by depth zone.

Potamogeton robbinsii did not occur at the sample sites in 1991, but its frequency and density has been steadily increasing, epsecially in the deeper depth zones (Figure 13, 14). In June 2001, *P. robbinsii* was co-dominant in the 10ft depth zone. In August 2001, it was co-dominant in the 1.5-5ft depth zone and



dominant in the 5-10ft depth zone.

Figure 13. Frequency of *Potamogeton robbinsii* by depth zone.

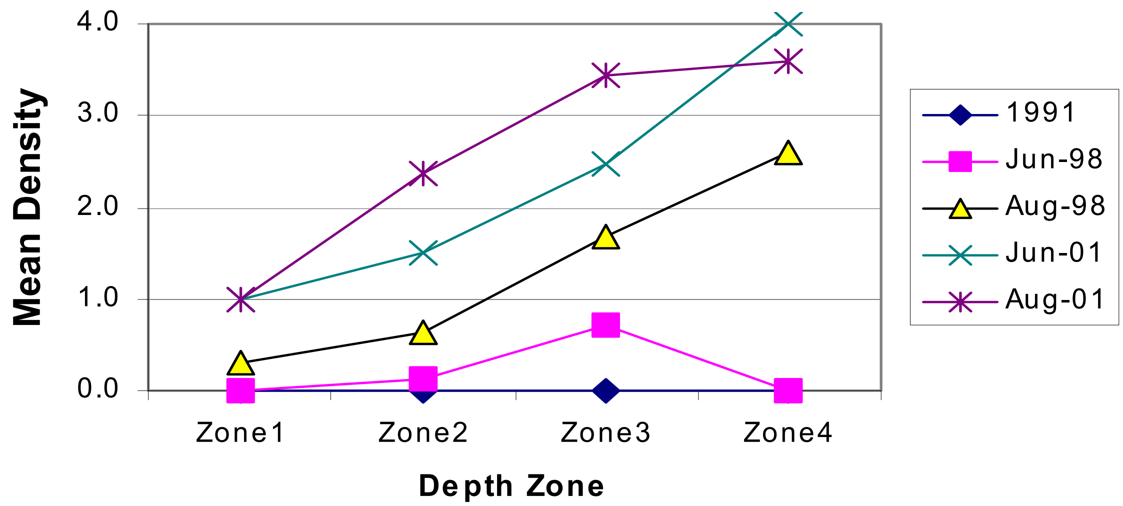
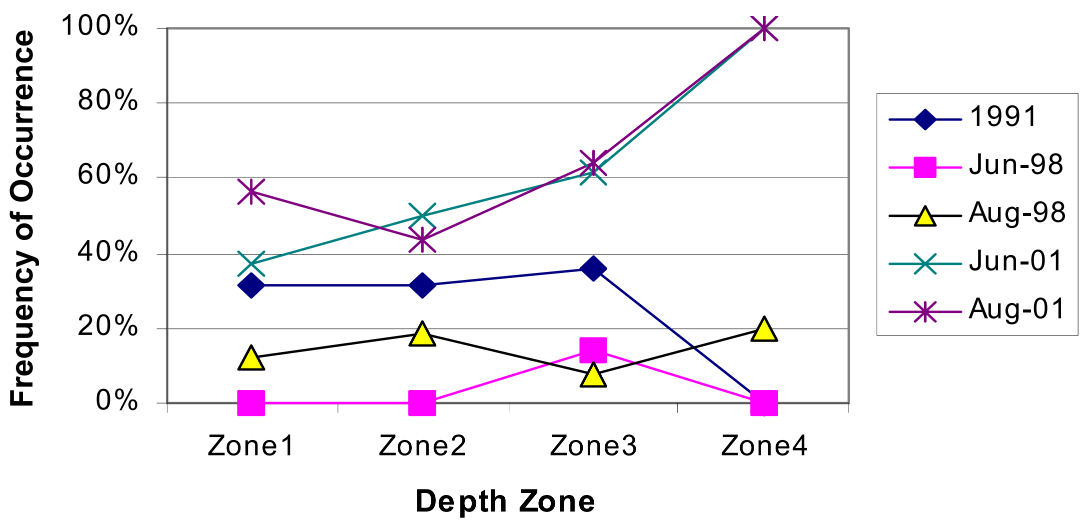


Figure 14. Density of *Potamogeton robbinsii* by depth zone.

In 1991, *C. demersum* had been the dominant species in the 10ft depth zone. In 1998, the frequency of *Ceratophyllum demersum* had decreased at the sample sites (Figure 15, 16). In 2001, the frequency and density of *C. demersum* increased to its highest



frequency and density (Figure 15, 16).

Figure 15. Frequency of *Ceratophyllum demersum* by depth zone.

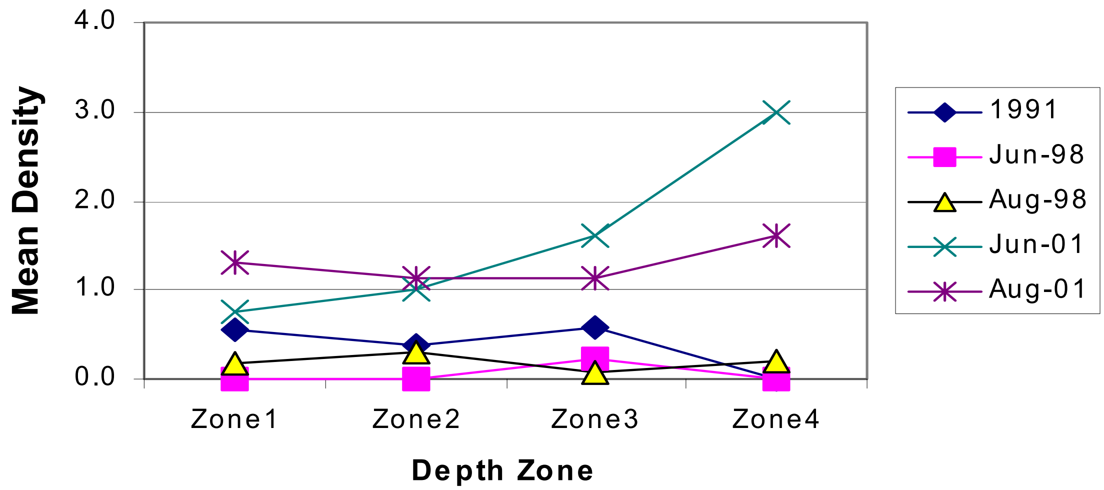


Figure 16. Density of *Ceratophyllum demersum* by depth zone.

THE COMMUNITY

The Coefficients of Community Similarity is a measure of the percent similarity between two communities. Coefficients less than 0.75 indicate that the two communities are only 75% similar and are considered significantly different.

The coefficients for Lake Hallie indicate that the late summer aquatic plant communities were significantly different each year (Table 8). The 1991 and 1998 communities were only 63% similar and the 1998 and 2001 August plant communities were only 66% similar. The change in the late summer plant communities accumulated over the ten years so that the 1991 and 2001 communities were only 53% similar (Table 8).

The early summer (June) aquatic plant communities have also changed significantly. The June 1998 and June 2001 plant communities were only 65% similar (Table 8).

The plant communities in Lake Hallie change during the year due to the dominance and later die-back of *Potamogeton crispus.* In 1998, there was a significant change, as expected, in the plant community with the die-back of *P. crispus;* the June and August plant communities were only 70% similar. However, in 2001, there was not a significant change; the June and August plant communities were 78% similar (Table 8).

Table 8. Coefficients of Community Similarity

	Coefficient	% Similarity
Late Summer Plant Community		
1991-98	0.6301	63%
1998-2001	0.6602	66%
1991-2001	0.5267	53%
June Plant Community		
1998-2001	0.6475	65%
June-August		
1998	0.6963	70%
2001	0.7799	78%

Different parameters and indices can be used to determine what changes have occurred in the plant community. In Lake Hallie, several parameters decreased from 1991 to 1998 and subsequently increased from 1998-2001: the number of species at the sampling sites, the percent of the littoral zone that was vegetated, the percent coverage of emergents, submergent and free-floating species and the Floristic Quality (discussed later in this document) (Table 9).

Simpson's Diversity Index decreased from good diversity in 1991 to average diversity in 2001. An index of 1.0 would mean that each individual plant in the lake was a different species (the most diversity achievable).

Table 9. Changes in the Lake Hallie Macrophyte Community

	1991	1998	2001	Change 1991-2001	% Change
Number of Species	19	14	20	1	5%
% Littoral Zone Vegetated	100	94	100	0	0
%Sites w/ Emergernts	14	4	20	6	43%
%Sites w/ Submergernts	98	94	96	-2	-2%
%Sites w/ Free-floating	69	42	88	19	28%
Simpson's Diversity Index	0.89	0.85	0.84	-0.05	-6%
Floristic Quality	19.8	17.8	20.5	0.76	4%

The Aquatic Macrophyte Community Index (AMCI) for Lake Hallie was slightly below average (40) for lakes in Wisconsin in 1991 and early 1998. The quality increased to average in late summer 1998 and above average quality in early 2001 (Table 10). The highest value for this index is 60.

Table 10. Aquatic Macrophyte Community Index

Category	July 1991	June 1998	August 1998	June 2001	August 2001
Maximum Rooting Depth	6	6	6	6	6
% Littoral Zone Vegetated	10	10	10	10	10
Simpson's Diversity	9	8	9	9	8
# of Species	5	5	3	7	7
% Submersed Species	7	8	8	7	5
% Sensitive Species	0	0	4	4	4
Totals	37	37	40	43	40

The Average Coefficients of Conservatism for Lake Hallie, 1991-2001, were in the lowest quartile for all Wisconsin lakes and lakes in the North Central Hardwood Region (Table 11). This indicates that Lake Hallie was in the group of lakes that are most disturbance tolerant, likely from being subjected to disturbance.

Table 11. Mean Coefficient of Conservatism and Floristic Quality of Little Falls Lake, Compared to Wisconsin Lakes and Region Lakes.

	($\hat{c}$) Average Coefficient of Conservatism	(I) Floristic Quality	(I) Based on Relative Frequency
Wisconsin Lakes	5.5, 6.0, 6.9*	16.9, 22.2, 27.5*	
NCHF	5.2, 5.6, 5.8*	17.0, 20.9, 24.4*	
1991	4.94	19.75	19.83
June 1998	4.44	17.75	12.76
August 1998	4.92	17.75	16.62
June 2001	4.83	20.51	17.65
August 2001	4.83	20.51	19.95

* upper limit of lower quartile, mean, lower limit of upper quartile
Average Coefficient of Conservatism for all Wisconsin lakes ranged from a low of 2.0 (the most disturbance tolerant) to a high of 9.5 (least disturbance tolerant).
The lowest Floristic Quality was 3.0 (farthest from an undisturbed condition) and the high was 44.6 (closest to an undisturbed condition).
The North Central Hardwood Forest Region (NCHF) is the region in which Lake Hallie is located.

The Floristic Quality Index for Lake Hallie (1991-2001) was below the mean for Wisconsin Lakes and for lakes in the North Central Hardwood Region (Table 11). This indicates that Lake Hallie was farther from an undisturbed condition than the average lake in Wisconsin and the North Central Hardwood Region. The disturbance appears to have increased during 1998 and decreased in 2001.

Disturbances can be of many types:

1) Direct disturbances to the plant beds result from boat traffic, plant harvesting, chemical treatments, the placement of docks and other structures, etc.
2) Indirect disturbances can be the result of factors that impact water clarity and thus stress species that are more sensitive: resuspension of sediments, sedimentation from erosion, increased algae growth due to nutrient inputs.
3) Biological disturbances include the introduction of a non-native or invasive plant species, grazing from an increased population of aquatic herbivores, destruction of plant beds by the fish population, etc.

These values and conclusions were based only on the occurrence of disturbance-tolerant and disturbance-sensitive species. The frequency or dominance of these tolerant or sensitive species in the plant community in Lake Hallie was not taken into consideration. The Floristic Quality was recalculated by weighting each species Coefficient of Conservatism with its relative frequency.

The resulting values, based on the relative frequency of tolerant and intolerant species, provides more detail. The plant community in Lake Hallie was below the mean for all Wisconsin lakes and all North Central Hardwood Region Lakes in 1991, in the lowest quartile in 1998 and below the mean in 2001. The Floristic Quality decreased from 1991 to 1998 and increased in 2001, indicating an increased disturbance in 1998 and decreased disturbance in 2001.

V. DISCUSSION

Based on 2001 water quality data, Lake Hallie is a mesotrophic lake with good water quality and fair water clarity. However, the dense growth of filamentous algae and aquatic plants indicate a eutrophic lake. Filamentous algae was abundant in Lake Hallie and has increased since 1991.

Water monitoring conducted by the DNR in 1991 and 2001 indicate that the nutrient concentrations and planktonic algae have decreased since 1991. In spite of the decrease in nutrients and planktonic algae, the water clarity has decreased during the same time period. There may be siltation and erosion problems that are impacting water clarity.

Although water clarity has declined overall since 1991, volunteer monitoring data indicates that water clarity has been increasing since 1997. The aquatic plant harvesting program may be removing enough plant material to decrease nutrient release and therefore improve water clarity.

The Plant Community

The adequate nutrients, high frequency of favorable silt sediments, gradual-sloped littoral zone and shallow depths over much of the lake favor plant growth.

The aquatic plant community in Lake Hallie is characterized by high density of growth, an average diversity, average quality (AMCIndex) and a greater than average tolerance to disturbance. Dense plant growth is found throughout Lake Hallie to the maximum depth of the lake; aquatic plants were found at 94-100% of the sites and more than 90% of the sites in all depth zones. The highest occurrence and density of plants was found in the July 1991 survey and in the 0-1.5 foot depth zone in all surveys. The most prevalent species are found throughout the lake.

Elodea canadensis (common waterweed) has been the dominant plant species in Lake Hallie, especially in the 1.5-5ft depth zone; *Wolffia columbiana* (watermeal) became the dominant species in August of 2001. Common waterweed is adapted to low water clarity due to the placement of its chloroplasts near the leaf surface; watermeal is adapted to low clarity because of its growth on the surface of the water.

Potamogeton crispus (curly-leaf pondweed) was the sub-dominant plant species in June 1998. The dominance of this non-native species declined in August and in 2001. The frequency and density of *P. crispus* declined substantially since June 1998.

Changes in the Plant Community

The plant community in Lake Hallie has changed significantly, both during the year and from year to year.

JUNE TO AUGUST CHANGES

A plant community with abundant *Potamogeton crispus* (curly-leaf pondweed) would be expected to change significantly from June to August due to the early summer dominance and mid-summer die-back of the *P. crispus.* Curly-leaf pondweed survives the winter under the ice and resumes growth early in the year while the water is still cold. This provides a head start for growth. As the water temperature rises in early June, curly-leaf reaches its peak growth, produces turions (seed-like structures) and undergoes a die-back. The turions will sprout in the fall when water temperatures cool and these sprouts live through the winter under the ice. In 1998, the June plant community was only 70% similar to the August community with the decline of *Potamogeton crispus* **least** noticeable in the deeper depth zones. This is likely due to the colder water in the deeper zones that could support it further into the summer.

The June plant communities have changed. The June 1998 community was only 65% similar to the June 2001 community and the June and August plant communities in 2001 were not significantly different. This suggests that the curly-leaf pondweed has declined to the extent that it may not be impacting the plant community as it once did. The June to August decline of *P. crispus* in 1998, though not sufficient to cause a significant change in the plant community, was **most** noticeable in the deeper depth zones, likely due to mechanical harvesting.

CHANGES AMONG YEARS

The August plant communities have changed significantly. The Lake Hallie plant community in 2001 was only 66% similar to the 1998 community and only 53% similar to the 1991 plant community, based on the Coefficients of Community Similarity.

Simpson's Diversity Index indicates that the diversity of aquatic plant species in Lake Hallie declined from good diversity in 1991 to average diversity in 1998 and 2001. Although the diversity index has decreased, the number of species at the sampling sites has increased.

Other changes in the plant community in Lake Hallie from 1991 to 2001:

1) The decrease in *Chara* sp. (muskgrass) and *Spriodela polyrhiza* (greater duckweed).
2) The increased dominance of *Potamogeton robbinsii* (fern-leaf pondweed).
3) An increase in the quality of the plant community as measured by the AMCIndex.
4) The decrease in total occurrence and density of aquatic plant

growth.

Some changes may be attributable to the mechanical harvesting. These parameters decreased from 1991 to 1998 as the curly-leaf pondweed was becoming more dominant in Lake Hallie and subsequently increased from 1998 to 2001 after the mechanical harvesting program was put into effect.

a) number of species occurring at the sample sites
b) Floristic Quality Index (which suggests and increase and then decrease in disturbance)

Potamogeton crispus (curly-leaf pondweed) may have been determining the composition of the aquatic plant community in Lake Hallie via light availability to other species and cycling of nutrients into the lake during the growing season.

Light availability would be decreased by the early season dominance and shading of the other species of curly-leaf pondweed and the lower water clarity resulting from algae growth after its die-back. Many of the species in Lake Hallie (*Ceratophyllum demersum, Eleocharis acicularis, Elodea canadensis, Lemna minor, Potamogeton foliosus, P. pusillus, Sagittaria, Spirodela polyrhiza, Typha latifolia*) are tolerant of lower water clarity.

The nutrient release from the decaying curlyleaf pondweed cycles nutrients into the lake during the grwoing season. *Ceratophyllum demersum, Chara, Elodea canadensis, Lemna minor, Potamogeton robbinsii* and *Spirodela polyrhiza* can grow to over-abundance when there is an excess of nutrients in the lake (Nichols and Vennie 1991).

Eleocharis robbinsii has disappeared from Lake Hallie. It is a species of special concern and may be a sensitive species whose decline may indicate disturbance.

Potamogeton amplifolius is considered an indicator of good water clarity and has increased slightly since 1998. Its increase may indicate the removal of curly-leaf pondweed is reducing shading when it first sprouts.

The occurrence of natural shoreline (wooded, shrub and native herbaceous growth) on Lake Hallie was high. Native herbaceous cover occurred at three-quarters of the sites. Although natural shoreline was frequent, cultivated lawn occurred at more than half of the sites and covered more than one-third of the shore. Cultivated lawn can result in increased run-off of fertilizers, pet wastes and other nutrients. Expanding and preserving the buffer of natural vegetation along the shore will protect the water quality of the lake from toxic run-off, nutrient run-off and erosion.

VI. CONCLUSIONS

Lake Hallie is a eutrophic lake with good water quality, fair water clarity, periodic planktonic algae blooms and abundant filamentous algae.

The plant community in Lake Hallie is of average quality for Wisconsin lakes and is characterized by average diversity, dense plant growth and a greater than average disturbance to the plant community. Because of the good water clarity and shallow basin, vegetation can colonize the entire lake bed and will require management. The aquatic plant community has changed significantly since 1991.

Elodea canadensis has been the dominant species within the plant community and curly-leaf pondweed is sub-dominant during its peak growth in June. *Wolffia columbiana* became the dominant species in August 2001.

Several changes have been seen since the harvesting program began in 2000.

1) Water clarity has increased since 1997.
2) The dominance of *Potamogeton crispus* has decreased, especially in the deeper depth zones
3) The Floristic Quality has increased, suggesting the harvesting is causing less disturbance to the plant community than the dominance of *P. crispus* caused
4) Less significant change between the June and August plant communities, implying the *P. crispus* is having less impact on the aquatic plant community
5) The number of species at the sampling sites has increased
6) The frequency of *Potamogeton amplifolius*, an aquatic plant that is valuable for habitat, has increased.

A healthy aquatic plant community plays a vital role within the lake community. This is due to the benefits that plants provide in
1) improving water quality 2) providing valuable resources for fish and wildlife 3) resisting invasions of non-native species and 4) checking excessive growth of tolerant species that could crowd out the more sensitive species, therefore reducing the diversity.

1) Plant communities improve water quality in many ways: they trap nutrients, debris, and pollutants entering a water body; they absorb and break down some pollutants; they reduce erosion by damping wave action and stabilizing shorelines and lake bottoms; they remove nutrients that would otherwise be available

for algae blooms (Engel 1985).

2) Aquatic plant communities provide important fishery and wildlife resources (Table 12). Plants (including algae) start the food chain that supports many levels of wildlife, and at the same time produce oxygen needed by animals. Plants are used as food, cover and nesting/spawning sites by a variety of wildlife and fish. Cover within the littoral zone should be about 25-85% to support a healthy fishery.

The plant growth in Lake Hallie in 2001 provided 100% cover within the littoral zone for habitat. This amount of plant growth provides over-abundant cover and may limit fish and wildlife use.

Compared to non-vegetated lake bottoms, plant beds support larger, more diverse invertebrate populations that in turn will support larger and more diverse fish and wildlife populations (Engel 1985). Additionally, mixed stands of plants support 3-8 times as many invertebrates and fish as monocultural stands (Engel 1990). Diversity in the plant community creates more microhabitats for the preferences of more species. Plant beds of moderate density support adequate numbers of small fish without restricting the movement of predatory fish (Engel 1990).

Management Recommendations

1) Preserve and expand the natural buffer zones of native vegetation around the lake. This will benefit water quality and wildlife habitat. Replace mowed lawn at the shoreline with a buffer of natural vegetation 50 feet deep.
2) Cooperate with programs to manage run-off and erosion in the watershed.
3) Develop an aquatic plant management plan. Include mechanisms for modifications as the plant community changes.
4) Develop a lake association budget that will provide funds for repair and maintenance of the harvester and pay harvester operators.
5) Continue the mechanical harvesting program during the early season to remove curly-leaf pondweed from Lake Hallie before its die-off and thus the nutrients that are released during the die-back. Reducing this nutrient source may eventually reduce the algae blooms.
6) Harvest in mid and late summer in dense plant beds to improve habitat.
    a) Harvesting improves fish habitat by opening up cruising lanes for predatory fish. These openings improve the hunting success of the predatory fish and promote a better balanced fishery.
    b) Avoid harvesting in areas with valuable habitat plants
    c) Harvesting will immediately open areas for easier

boating.

Lake Hallie's proximity to an urban area makes it an important resource that deserves protection. These practices will protect the water quality and wildlife habitat in the lake.

Lake Hallie Aquatic Plant Species

Scientific Name	**Common Name**	**I. D. Code**
Emergent Species		
1) *Calla palustris*	water arum	calpa
2) *Carex comosa*	bristly sedge	carco
3) *Eleocharis robbinsii*	Robbin's spikerush	elero
4) *Impatiens biflora*	pale jewelweed	impbi
5) *Iris versicolor*	blue flag iris	irive
6) *Juncus effusus*	soft rush	junef
7) *Leersia oryzoides*	rice cut-grass	leeor
8) *Myosotis laxa*	smaller forget-me-not	myola
9) *Phalaris arundinacea*	reed canary grass	phaar
10) *Rorippa nasturtium-aquatica*	water-cress	rorna
11) *Sagittaria rigida*	stiff arrowhead	sagri
12) *Scirpus validus*	softstem bulrush	sciva
13) *Typha angustifolia*	narrow-leaf cattail	typan
14) *Typha latifolia*	common cattail	typla
Floating Species		
15) *Lemna minor*	small duckweed	lemmi
16) *Lemna trisulca*	forked duckweed	lemtr
17) *Spirodela polyrhiza*	greater duckweed	spipo
18) *Wolffia columbiana*	common watermeal	wolco
Submergent Species		
19) *Ceratophyllum demersum*	coontail	cerde
20) *Chara* sp.	muskgrass	chasp
21) *Elatine minima*	waterwort	elami
22) *Eleocharis acicularis*	needle spikerush	eleac
23) *Elodea canadensis*	common water-weed	eloca
24) *Najas flexilis*	northern water-nymph	najfl
25) *Nitella* sp.	nitella	nitsp
26) *Potamogeton amplifolius*	large-leaf pondweed	potam
27) *Potamogeton crispus*	curly-leaf pondweed	potcr
28) *Potamogeton foliosus*	leafy pondweed	potfo
29) *Potamogeton pusillus*	slender pondweed	potpu
30) *Potamogeton robbinsii*	fern-leaf pondweed	potro
31) *Potamogeton zosteriformis*	flatstem pondweed	potzo
32) *Ranunculus longirostris*	white watercrowfoot	ranlo